Multiphoton detection of THz frequency light with sensitive Graphene-Based Tunnel Field-Effect Transistors

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Abstract: Detection of 3 THz radiation by tunnel field effect transistors based on bilayer graphene – hexagonal boron nitride heterostructures. We achieved noise equivalent power ~1 $pWHz^{-1/2}$ with a power dynamic range exceeding five orders of magnitude.

Sensitive photodetectors with large quantum efficiencies and broad dynamic ranges are essential components for the implementation of photonic quantum platforms. In the Terahertz (THz) frequency range, with photon energies of few meV, the development of these devices is extremely challenging owing to the lack of high-absorption materials and the concurring thermal effects that affect their noise figure. Recent advancements towards THz detectors with enhanced sensitivity include the use of field-effect transistors based on two-dimensional (2D) materials, whose unique optoelectronic properties enable the activation of different physical mechanisms to detect far-infrared photons [1].

In this work, we develop antenna-coupled tunnel field effect transistors (TFETs) [2] based on hBN-encapsulated bilayer graphene (BLG) to detect THz radiation (Fig.1a,b). In a TFET, the strong photoresponse is due to the realization of a tunnel junction along the channel by applying an out-of-plane electric field, $E_{\perp}$, which modifies the energy gap of BLG, leading to a steep increase in the FET transconductance. The main detection figures of merit, minimum detectable power (MDP), and noise equivalent power (NEP), were evaluated at ~3 THz, reaching MDP ~5 nW and NEP = 1 $pWHz^{-1/2}$, respectively, with a power dynamic range exceeding five orders of magnitude (Fig.1c). By analysing the effect of $E_{\perp}$ on the responsivity (Fig.1d,e), we found that three physical mechanisms contribute to the photodetection [3]: photothermoelectric effect, plasmonic and tunneling rectifications. Our results open intriguing perspectives for the statistical analysis of quantum intensity correlations in non-classical light sources operating in the underexploited THz range, between technologically mature domains (microwave, visible, near-infrared) that currently dominate the field of quantum technologies.

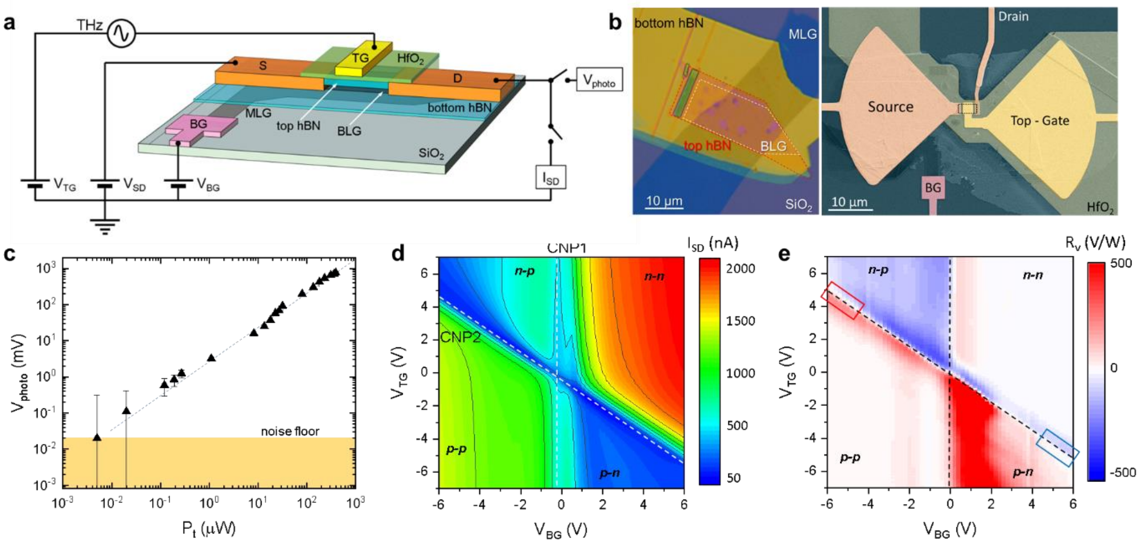

Fig. 1 (a) Schematic of the active element of the TFET: an hBN-encapsulated dual-gated BLG transistor. (b) Optical image of the layered material heterostructure and false color SEM image of a four-terminals TFET coupled to a planar 3 THz bow-tie antenna. BG refers to the back-gate electrode. (c) Measurement of the TFET output signal vs. optical input power. The detector shows good linearity with a dynamic range of five orders of magnitude (setup limited). (d) Electrical transport characterization: source-drain current map measured as a function of the voltages applied to the top- and back-gates. (e) Corresponding responsivity map, showing the activation of different photodetection mechanisms.

References

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